

APPENDIX III TO PART 86—CONSTANT VOLUME SAMPLER FLOW CALIBRATION

The following calibration procedure outlines the equipment, the test setup configuration, and the various parameters which must be measured to establish the flow rate of the constant volume sampler pump. All the parameters related to the pump are simultaneously measured with the parameters related to a flowmeter which is connected in series with the pump. The calculated flow rate (ft³/rev@ pump inlet absolute pressure and temperature) can then be plotted versus a correlation function which is the value of a specific combination of pump parameters. The linear equation which relates the pump flow and the correlation function is then determined. In the event that a CVS has a multiple speed drive, a calibration for each range should be performed.

This calibration procedure is based on the measurement of the absolute values of the pump and flowmeter parameters that relate the flow rate at each point. Three conditions must be maintained to assure the accuracy and integrity of the calibration curve. First, the pump pressures should be measured at taps on the pump rather than at the external piping on the pump inlet and outlet. Pressure taps that are mounted at the top and bottom center of the pump drive headplate are exposed to the actual pump cavity pressures, and therefore reflect the absolute pressure differentials. Secondly, temperature stability must be maintained during the calibration. The laminar flowmeter is sensitive to inlet temperature oscillations which cause the data points to be scattered. Gradual changes (± 2°F) in temperature are acceptable as long as they occur over a period of several minutes. Finally, all connections be-

tween the flowmeter and the CVS pump must be absolutely void of any leakage.

During a CVS emissions test the measurement of these same pump parameters enables the user to calculate the flow rate from the calibration equation.

After the calibration curve has been obtained, a verification test of the entire system can be performed by injecting a known mass of gas into the system and comparing the mass indicated by the system to the true mass injected. An indicated error does not necessarily mean that the calibration is wrong, since other factors can influence the accuracy of the system.

Equipment:

The following list of equipment will be needed to perform this calibration procedure. Figure 1 illustrates a typical equipment arrangement used for calibration. All of the equipment involved should conform to the range and accuracy as specified in Figure 1.

Equipment List:

1. LFE—Laminar Flowmeter
2. Micromanometer
3. Thermometer
4. Timer
5. U-Tube Manometers
6. Temperature Indicator with type J Thermocouples
7. A variable flow restrictor with appropriate piping to connect the CVS pump and LFE.

After the system has been connected as shown in Figure 1, set the variable restrictor in the wide open position and run the CVS pump for twenty minutes. Record the calibration data.

CALIBRATION DATA MEASUREMENTS

Parameter	Symbol	Units	Tolerance
Barometric pressure (corrected)	P _B	"Hg	±.01 "Hg.
Ambient temperature	T _A	° F	±.5° F.
Air Temperature into LFE	ETI	° F	±.1° F.
Pressure depression upstream of LFE	EPI	"H ₂ O	±.1"H ₂ O.
Pressure drop across the LFE matrix	EDP	"H ₂ O	±.005"H ₂ O.
Air temperature at CVS pump inlet	PTI	° F	±.5° F.
Pressure depression at CVS pump inlet	PPI	"Fluid	±.05"Fluid.
Specific gravity of manometer fluid	Sp. Gr.
Pressure head at CVS pump outlet	PPO	"Fluid	±.05"Fluid.
Air temperature at CVS pump outlet (optional)	PTO	° F	±.5° F.
Pump revolutions during test period	N	Revs	None.
Elapsed time for test period	t	Seconds	±.05 Seconds.

NOTE: The fluid level in the manometer tube should stabilize before the reading is made and the elapsed time for revolution counting should be greater than 120 seconds.

Reset the restrictor valve to a more restricted condition in an increment of pump inlet depression (about 4" H₂O) that will yield a minimum of six data points for the total calibration.

Allow the system to stabilize for 3 minutes and repeat the data acquisition.

Data Analysis:

The data recorded during the calibration are to be used in the following calculations.

1. The air flow rate at each test point is calculated in standard cubic feet per minute (Q_s) from the flowmeter data using the manufacturer's prescribed method.

2. The air flow rate is then converted to pump flow, V_o, in cubic feet per revolution at absolute pump inlet temperature and pressure.

$$V_o = Q_s/n \times T_p/530 \times 29.92/P_p$$

where:

Q_s=Meter air flow rate in standard cubic feet per minute (flowmeter standard conditions are 70°F, 29.92 "Hg).

n=Pump speed in revolutions per minute.

P_p=Absolute pump inlet pressure, in ("Hg).

P_p=P_B-PPI (SP.GR./13.57), T_p = PTI + 460.

3. The correlation function at each test point is then calculated from the calibration data, as follows:

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ΔP_p = The pressure differential from pump inlet to pump outlet in ("Hg).

$$\Delta P_p = P_e \cdot P_p$$

P_e =Absolute pump outlet pressure, in ("Hg).

$$P_p = P_B + PPO \text{ (Sp. Gr./13.57)}$$

See § 86.177–22 for other definitions.

4. A linear least squares fit is performed to generate the calibration equations which have the forms

$$\begin{aligned} V_o &= D_o \cdot M(X_o) \\ n &= A \cdot B(P_p) \end{aligned}$$

D_o , M , A , and B are the slope-intercept constants describing the lines.

A CVS system that has multiple speeds should be calibrated on each speed used. The calibration curves generated for the ranges will be approximately parallel and the intercept values, D_o , will increase as the pump flow range decreases.

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If the calibration has been performed carefully, the calculated V_o values from the equation will be within $\pm 50\%$ of the measured value of V_o . Values of M will vary from one pump to another, but values of D_o for pumps of the same make, model, and range should agree within ± 3 percent of each other. Particulate influx from use will cause the pump slip to decrease as reflected by lower values for M . Calibrations should be performed at 0, 30, 100, 200, 400, etc. hours of pump operation to assure the stability of the pump slip rate. Analysis of mass injection data will also reflect pump slip stability.

CVS System Verification:

The following technique can be used to verify that the CVS and analytical instruments can accurately measure a mass of gas that has been injected into the system.

1. Obtain a small cylinder that has been charged with pure propane or carbon monoxide gas (caution—carbon monoxide is poisonous!). Critical flow orifice devices can also be used for constant flow metering.
2. Determine a reference cylinder weight to the nearest 0.01 gram.
3. Operate the CVS in the normal manner and release a quantity of pure propane or carbon monoxide into the system during the sampling period.
4. The calculations of § 86.177–22 are performed in a normal way except, in the case of propane, the density of propane (17.30 grams/cu.ft./carbon atom) is used in place

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of the density of exhaust hydrocarbons. In the case of carbon monoxide, the density of 32.97 grams/cu. ft. is used.

5. The gravimetric mass is subtracted from the CVS measured mass and then divided by the gravimetric mass to determine the percent accuracy of the system.

6. The cause for any discrepancy greater than ± 2 percent should be found and corrected. The following list of parametric errors may assist the operator in locating the cause of large errors.

Positive Error (Indication is higher than true value):

1. Calculated V_o is greater than actual V_o .
 - a. Original calibration in error.
2. Pump inlet temperature recorder is reading low. A 6° F. discrepancy will give a 1 percent error.
3. Pump inlet pressure indicator is reading high. A 3.5 in. H_2O high reading will give 1 percent error.
4. Background concentration reading is too low. Check analyzer zero. Check leakage at floor inlet.
5. Analyzer is reading high. Check span.

6. Barometer reading is in error (too high). Barometric pressure reading should be gravity and temperature corrected.

7. Revolution counter is reading high (Check pump speed and counters.)

8. Mixture is stratified causing the sample to be higher than the average concentration in the mixture. Negative Error (Indication is lower than true value):

1. Calculated V_o is less than actual V_o .
 - a. Original calibration in error.
 - b. Pump clearances decreased due to influx of some surface adherent material. Recalibration may be needed.
2. Pump inlet temperature recorder is reading high.
3. Pump inlet pressure indicator is reading low.
4. Background concentration reading is too high.
5. Analyzer is reading low.
6. Barometer reading is in error (too low).
7. Revolution counter is reading low.
8. There is a leak into the sampling system. Pressure check the lines and fittings on the intake side of sample transfer pumps on both the CVS and analyzer console.

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